TABLE 3.—*Summary of exceptions to curves*

BASIN CURVES

	July 1–Dec. 15, Apr. 1–May 31	Dec. 16–Mar. 31	June 1–30
1. Floods but precipitation over basin below minimum	26	35	1
Number under 1 explained	4	30	0
Net exceptions unexplained	22	5	1
2. No floods but precipitation over basin above minimum	14	33	1
Number under 2 explained	6	28	0
Net exceptions unexplained	8	5	1

CURVES FOR GULF, CENTRAL, AND WESTERN STORMS

	Oct. 1–Dec. 15, Apr. 1–June 15	Dec. 16–Mar. 31
1. Floods, ample precipitation over basin, deficient over lines 1 and 2	17	10
2. Floods, deficient precipitation over basin, ample over lines 1 and 2	1	10
3. Floods, deficient precipitation over basin, deficient over lines 1 and 2	10	8
4. No floods, deficient precipitation over basin, ample over lines 1 and 2	28	34
5. No floods, ample precipitation over basin, deficient over lines 1 and 2	5	1
6. No floods, ample precipitation over basin, ample over lines 1 and 2	2	16

CURVES FOR ATLANTIC COAST STORMS

	Oct. 1–June 15
1. Floods, ample precipitation over basin, deficient over Knoxville, Tenn	3
2. Floods, deficient precipitation over basin, ample over Knoxville, Tenn	1
3. Floods, deficient precipitation over basin, deficient over Knoxville, Tenn	3
4. No floods, deficient precipitation over basin, ample over Knoxville, Tenn	2
5. No floods, ample precipitation over basin, deficient over Knoxville, Tenn	0
6. No floods, ample precipitation over basin, ample over Knoxville, Tenn	2

(3) Flood predictions will be made throughout the entire year, utilizing all available Cheat Basin meteorological data, depending mainly on diagrams that are based on Cheat River preflood stages and Cheat Basin average 48-hour precipitation.

The flood predictions in this item are in no way dependent on storm paths and precipitation at southwestern stations. However, all flood predictions under item (2) will be confirmed or discredited by information made available at this third stage of prediction. About 88 per cent of the predicted floods will occur.

(4) Flood predictions will be made, throughout the entire year on the basis of the increasing and crest stages for Rowlesburg floods. Practically 100 per cent of the Lake Lynn floods can be accurately predicted by this means.

Nearly all of the meteorological data for this flood prediction study were obtained at the Pittsburgh office of the United States Weather Bureau, and the authors desire to express their appreciation to W. S. Brotzman and his assistants for their courtesy and helpfulness in making available the vast amount of data that were needed. Assistance on this paper also has been rendered by a large number of other persons, and the authors hereby gratefully acknowledge such assistance.

NORTHERS OF THE GULF OF TEHUANTEPEC [1]

551.55 (261.64)

By WILLIS EDWIN HURD

The Isthmus and Gulf of Tehuantepec occupy a relatively unimportant position geographically, but nevertheless constitute a region that is unique in a meteorological sense. The isthmus, which separates the Gulf of Mexico from the Pacific Ocean, lies near the southeastern extremity of the Mexican Republic, with a least width of about 125 miles, although the distance by way of the Tehuantepec Railway from Puerto, Mexico, on the Atlantic to Salina Cruz on the Pacific side is 188 miles. For some 60 or 70 miles along that part of the Sierra Madre range that traverses the isthmus, the hills and highlands shrink many hundred feet in elevation, being mostly between 1,000 and 2,000 feet high, although at the highest point on the railway track the altitude is as low as 688 feet. There is thus formed a natural pass, or spillway, from one ocean to the other. The isthmus lies almost due south, across the Gulf of Mexico, from the Great Plains of North America, across which sweep unimpeded the continental anticyclones. Frequently in the colder season the air masses reach the Gulf, which thus becomes an atmospheric reservoir, the walls of which are the semi-inclosing continent. When the head of air which presses on down across the Bay of Campeche becomes too great, a part of the surplus overflows across the spillway of the isthmus, and rushes in a torrent down the opposite slopes and across the open gulf to the southward.

The Gulf of Tehuantepec, though comparatively small in area, is nevertheless a great roadstead, facing the Pacific in a direction slightly west of south, its visible boundary comprising approximately the southernmost 300 miles of the Mexican Pacific coast line. It is traversed by the shipping lines between the Panama Canal and various Pacific ports, and therefore the weather conditions which may be experienced here have an important bearing on navigation. Any study of the atmospheric overflows, or northers, of this gulf, therefore, has a practical as well as a scientific application.

The norther as such should not be confused with other northerly gales that sometimes occur over the Gulf of Tehuantepec. During the wet season—June to October—one or more tropical cyclones of moderate to considerable intensity are likely annually to form over, or cross the waters of the gulf from the southeastward. Those that originate locally are less likely to produce severely disturbing weather in this locality than those that come in from the southward and have had a longer time in which to develop. Ordinarily little confusion arises in identifying the type of gale wind that may blow here. But since the mariner, while at the head of the gulf, might experience the northeasterly gales, without much barometric depression, of the northwestern quadrant of a cyclone passing to the southward, he might erroneously identify them as a norther, unless a

[1] The word "Tehuantepec," as applied by the native Indians to the range of hills of that name near the head of the Gulf, signifies the mountains of the man-eating beasts, referring to the dangerous carnivorous animals that once infested the region.—*W. E. H.*

veering of the gale into southeasterly, an undue cloudiness of the sky, or a suspicious swell from the southward, should set his conclusions aright. This error is least likely to be made in summer, when cyclones only of the two classes of storms are likely to occur, and most likely to be made in autumn, when the cyclone and norther seasons overlap. In this gulf the norther is known locally as the Tehuantepecer, and it introduces a far greater degree of rough weather, as a rule, with regard to extent of area covered, duration, and intensity, than do the gales of the cyclonic type.

The cyclone is of wholly local origin in the region of frequent calms and light variable winds common in summer to the gulf and surrounding waters. The Tehuantepecer, on the other hand, while a local wind, by reason of the topography of the region, depends entirely for its development and continued existence upon the presence of an anticyclone over the adjacent regions to the northward. Any high-pressure field from that direction that spreads down over the entire southern part of the Gulf of Mexico piles an excess of air upon the Bay of Campeche and the bordering lowland plains of the Mexican States of Vera Cruz and Tabasco, and thus creates the condition that initiates a norther over the closely neighboring waters of the Pacific. If the anticyclone is weak, the norther will be mild, so far as its wind strength is concerned, but will usually cause invigorating weather south of the isthmus. If, however, the high-pressure mass is heavily built up and cresting immediately north of the Gulf of Mexico, a strong, cool Tehuantepecer is the inevitable consequence. While this may cause brisk to heavy northerly gales over the upper gulf, it is much more certain of producing gales, and of greater severity, over the waters of the lower gulf. The reason is clear. Pour the waters of a broad stream into a narrow gorge and the result is a greatly intensified current. Similarly with the anticyclonic air wave that presses into the comparatively narrow mountain pass of the Isthmus of Tehuantepec and emerges as a tumultuous gale that often spreads for hundreds of miles upon the waters of the Pacific.

At Salina Cruz, the principal port of the Gulf of Tehuantepec, situated on the small bay of Salina Cruz, the prevailing wind throughout the year is from north-northeast, with the second most frequent wind from the north. From November to February the average force of the former is 6 on the Beaufort scale, or between 25 and 31 miles an hour in equivalent velocity. The force of the north winds during the same time is 4 to 5. The former blows on the average of 46 per cent of the time during the four months, and the north winds, 31 per cent. The percentage of occurrence diminishes toward May and June, and the force is greatly lessened. During the 9-year period (1908–1916), according to a record of the Observatorio Central de Tacubaya, the maximum wind force measured at Salina Cruz was 9 from north-northeast and occurred in February. This was a velocity at the rate of about 50 miles an hour. During the other months from November to April the highest force was 8 from the same direction. Usual published statements upon the northers at this port indicate that they blow here with great fury at times from late fall until early spring.

Weather reports from seamen traversing the waters of the Gulf of Tehuantepec during November to February, and occasionally in other months, attest to the violence and frequency of these northers, and as regards frequency it can not be assumed that the reports for any given time constitute a complete record of their prevalence. During the 5-year period (1924–1928) Tehuantepecers of gale force—8 to 12 on the Beaufort scale—were reported on 120 days. Of these about 23 per cent of the November and January days, 15 per cent of the February, and 13 per cent of the December days, are to be included. October, March, and April had an average of 1 strong norther day per month. In addition, 2 northers of force 7 were observed in May, both in 1928. Of the whole number, 1 was a northeast hurricane, occurring in January, 1924; 2 were north gales of force 11 (64 to 75 miles per hour), 1 occurring in November, 1928, and the other in December, 1925; and 9 were gales of force 10 (55 to 63 miles), distributed as follows: 1 each in November, 1925 and 1928; 4 in January, 1928; 1 each in January, 1925 and 1926; and 1 in April, 1927. One-tenth of the entire number are thus known to have been gales of the higher forces. All but one of these were from the directions northwest to northeast, with north and northeast prevailing. The exception—that of April, 1927—was from the east. The gale field variously covered all portions of the gulf, and often extended a few hundred miles to the southward in decreasing force. In several instances moderate to whole northeasterly gales blew simultaneously far down the Pacific Central American coast.

Among the premonitory signs of norther weather in the Gulf of Tehuantepec are often a hazy atmosphere, but with the customary light airs prevailing, and sunsets and sunrises deeply colored with red. Often there are grayish mists hanging over the Mexican and Guatemalan mountain tops. In Indian weather lore, when the summits of certain high peaks are cloud-capped, the norther is expected to begin blowing on the following day, and will continue to blow as long as the peaks remain clouded. The norther may set in leisurely, but more often it drives over the gulf in a sudden burst and very quickly stirs up a heavy sea. The storm wave due to this cause is peculiarly short and very high. A great quantity of water is blown out from the head of the gulf during the gale, and in consequence of a considerable piling up of it on either side, the normal sea currents are temporarily overcome by surface currents which flow along either shore toward the place of lowered level, and continue as long as the norther lasts. When the gale is severe the swell set up by the storm is transmitted below the Equator, the wash being noticed in the height of the season on the north coasts of the Galapagos Islands.

The onset of the norther may be accompanied by light to heavy rain, as the preliminary arched squall cloud, if any, advances, but this is usually followed by quickly clearing skies, except for passing cirrus forms. In other instances little or no cloudiness may occur throughout. The temperature drops as the gale comes in, but there is frequently little or no change in the barometer, unless there is a rise if the anticyclone reaches unusually far to the southward. Sometimes, however, a slight temporary fall is observed after the gale begins, and it is then that the erroneous impression may be created that a cyclone is working to the southward of the gulf. The wind usually blows between east-northeast and west-northwest; it may begin from an easterly point and back to a westerly. Occasionally it blows from the east in the lower reaches of the Gulf, or is deflected by the coast hills into east over the western approaches.

The gale may be of very brief duration, lasting only a few hours, or, with some intermission of intensity, may continue for several days. In November, 1928, it blew

from the 20th to the 26th. In January, 1924, vessels reported that it set in on the 5th and continued until the 9th, during a part of the time rising to the force of a hurricane. In December, 1923, it came as a whole gale (force 10), though not continuously, on four consecutive days. In all these instances strongly developed and persistent high pressure conditions prevailed over the Southern States of the Union. Of all the months included in the 5-year period, January, 1928, was the stormiest, with a known record of 11 days on which winds blew with velocities of from 40 to 75 miles an hour over the Pacific gulf. In the Gulf of Mexico during the same time only one norther was reported by a vessel, and that of force 8 only.

One of the most comprehensive sea reports of norther weather ever received by the Weather Bureau was furnished through the Hydrographic Office by Capt. Arthur Cocks, master of the British steamer *Nictheroy*, San Pedro toward the Panama Canal. While west of the Gulf of Tehuantepec late on the 27th of January, 1928, the wind experienced was light southeasterly and sea oily calm. Quoting from the report:

> At 10:20 p. m. a black cloud shaped as an arch rose from the eastern horizon. At 10:45 p. m. this cloud passed over the ship; by then it had assumed the shape of a perfect curve which extended from the northern to the southern horizon, the width of the cloud being that of a rainbow, the sky otherwise being cloudless, with stars, even those at the lowest altitude, showing brightly. Soon after the cloud passed, it was seen to lose the arch formation and commence to break up into small fleecy clouds, which very quickly disappeared and the sky was again cloudless. About 10 minutes later the wind came from the ESE. at force 3, accompanied by considerable easterly swell.

Abbreviating the report: Early on the 28th the wind backed into east, then northeast by east, and was blowing a fresh gale from that direction by 8 a. m. The sunrise that morning was very red, and the temperature of the air much lower than on the preceding day. At this time a radio report from a steamer 15 miles from shore near the head of the gulf gave the wind as a whole gale from north-northeast, barometer 30.18. At 2 p. m. of the 28th the *Nictheroy* had barometer at its lowest, 30.00 inches. At 4 p. m. the air temperature was 73°, wind northeast by north, force 9, seas very heavy, sky cloudless. Ship hove to. That day "the sun set rosy red in a low haze, the sky from northeast to southwest being purple in color." Conditions were similar at sunrise of the 29th, except that the wind was now northeast in a strong gale, although the sea was decreasing. The vessel was now in the western part of the gulf, while the crest of the causing anticyclone, pressure 30.60 inches, lay over central Texas. At 8 a. m. the temperature had fallen to 68°, and the *Nictheroy* had resumed her course, but it was not until after noon that the wind, then a fresh gale from north-northeast, began rapidly to moderate, and the temperature to rise. The features of the storm which the captain desired to emphasize were (1) the unusual formation of cloud which preceded the wind; (2) the oft-repeated occurrence of three very heavy seas following in succession when the sea was roughest; (3) the moderating of the sea before the decreasing of the wind.

Although the Tehuantepecer is a norther, and probably will always retain that common name, yet it must be recognized that there is a difference between it and the norther of the Plains States and the Gulf of Mexico. The norther to the eastward of the great North American mountain system is a true anticyclonic wind, and may therefore be classified as a gradient norther. The Tehuantepecer, on the contrary, is a wind of the opposite side of the Cordillera, is ordinarily little associated with pressure changes of moment, and is primarily a mere overflow of heaped up air through a mountain pass from the lower part of the basin in which the anticyclone operates. It is, therefore, a derivative or overflow norther, and might be classified as an orographic norther. When the conditions inducing the Tehuantepecer extend sufficiently far to the southward, other overflows of lesser volume appear to occur through the passes of Central America, producing local northeasterly winds on its Pacific coast of a similar character. One of these is found exemplified in the Bay of Papagayo, on the northwest coast of Costa Rica, and is known locally as the Papagayo. The same name seems to be applied to similar winds of neighboring parts of the coast, especially those of Nicaragua and Guatemala.

METEOROLOGICAL PROGRAM OF THE SEVENTH CRUISE OF THE "CARNEGIE," 1928–1931

By CHARLES F. BROOKS, Clark University, Worcester, Mass.

The nonmagnetic ship *Carnegie* is known the world over for its magnetic surveys of all the oceans during six cruises from 1909 to 1921. Now the ship, refitted and equipped for special oceanographic and meteorological work as well as for magnetic and atmospheric-electric, is well along on its seventh cruise, one which will carry it 110,000 miles in three years. The *Carnegie* is primarily a sailing vessel of 600 tons, with hemaphrodite brigantine rig. (See fig. 1.) It has also an auxiliary motor capable of 6 knots. The crew is 17 men, and the scientific staff, including Capt. J. P. Ault, numbers 8, 2 of whom, Dr. J. H. Paul and Oscar W. Torreson, have the meteorological observations as part of their duties.

The route covered through March, 1929, and that planned for the remainder of the cruise is shown in Figure 2. The *Carnegie* alternates hemispheres to avoid winter storms. Ports of call are few and far between. Sailing from Washington, May 1, 1928, the *Carnegie* for several days checked its magnetic instruments against indications of land parties, then after a few days at Newport News made a stormy and slow 29-day passage to Plymouth. Easterly and southeasterly winds and gales held up the vessel off the entrance to the English Channel for 10 days. A fortnight each was spent at Plymouth and Hamburg for the completion of the meteorological and oceanographic equipment and for repairs to the ship after the buffeting. Dr. H. U. Sverdrup, of the Geophysical Institute in Bergen, Norway, and research associate of the Carnegie Institution, inspected the vessel and assisted in the scientific installations at Hamburg. Also, many constructive suggestions were made by members of the *Meteor* expedition. The voyage to Reykjavik, July 7 to 20, and thence to Barbados July 27 to September 17, was moderately stormy in the north, but generally quiet in the south except for two gales, one of them in the southern part of the great September hurricane. From Barbados to Panama squalls helped and calms and head-winds delayed progress. At Balboa the ship was again dry-docked and made ready for a long circuit in the South Pacific. After leaving Balboa October 25, two weeks were required to get out of the Gulf of Panama against the constant southwesterly